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A CENSUS OF ULTRA-COMPACT DWARF GALAXIES IN NEARBY GALAXY CLUSTERS

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Abstract. Ultra-compact dwarf galaxies (UCDs) are predominately found in the cores of nearby galaxy clusters. Besides the Fornax and Virgo cluster, UCDs have also been confirmed in the twice as distant Hydra I and Centaurus clusters. Having (nearly) complete samples of UCDs in some of these clusters allows the study of the bulk properties with respect to the environment they are living in. Moreover, the relation of UCDs to other stellar systems in galaxy clusters, like globular clusters and dwarf ellipticals, can be investigated in detail with the present data sets. The general finding is that UCDs seem to be a heterogenous class of objects. Their spatial distribution within the clusters is in between those of globular clusters and dwarf ellipticals. In the colour-magnitude diagram, blue/metal-poor UCDs coincide with the sequence of nuclear star clusters, whereas red/metal-rich UCDs reach to higher masses and might have originated from the amalgamation of massive star cluster complexes in merger or starburst galaxies.

1 Introduction

Galaxy clusters are known to be the environments that harbour the largest number of early-type dwarf galaxies. Despite dwarf ellipticals (dEs) and dwarf spheroidals (dSphs), a new type of old, compact stellar systems with stellar masses in the range of faint dwarf galaxies ($\sim 10^7 M_\odot$) was identified in nearby galaxy clusters, the so-called ultra-compact dwarf galaxies (UCDs) (Hilker et al. 1999, Drinkwater et al. 2000). Although very similar to globular clusters (GCs) in many respects, UCDs show two main differences to them: they follow a mass-size relation (Haşegan et al. 2005) and show an elevated mass-to-light ratio in comparison to GCs of the same metallicity (Mieske et al. 2008a). The latter finding cannot be explained by simple stellar population models with a canonical IMF (Dabringhausen et al. 2008, Mieske & Kroupa 2008b). Both characteristics are valid for UCDs with

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Table 1. Number of UCDs (Cols. 3-5) and GCs/UCDs brighter than ω Cen (Cols. 6 and 7) within different cluster-centric radii as indicated in the second row. The last column gives the estimated completeness of UCD counts within one core radius.

Cluster	R_{core} [kpc]	N_{UCD}			$N_{>\omega\text{Cen}}$		C_{UCD} < R_c
		all	< 100kpc	< $0.5R_c$	all	< R_c	
Fornax	100	59	34	20	154	106	$\sim 90\%$
Hydra I	350	38	31	26	65	56	< 70%
Centaurus	220	28	20	22	< 40%
Virgo	350	> 25	> 25	> 20

masses exceeding $\sim 2 \times 10^6 M_{\odot}$ which corresponds to a luminosity limit of about $M_V < -11$ mag. Often this luminosity is used to divide UCDs from globular clusters. However, this does not mean that there might exist fainter UCDs and brighter GCs. This depends on the still unknown formation mechanisms of both types. One might think of ω Centauri and M54 as faint UCDs.

The main formation scenarios for UCDs can be divided into a galaxian and a star cluster origin. The former assume that UCDs are either the remnant nuclei of disrupted galaxies (e.g. Bekki et al. 2001) or genuine compact dwarf galaxies (e.g. Phillipps et al. 2001). The latter include the formation of UCDs in stellar supercluster complexes of merging galaxies (Fellhauer et al. 2002) or via ‘normal’ GC formation in giant molecular clouds (Mieske et al. 2002). Photometric and structural properties alone are not sufficient to decide whether UCDs are of star cluster or galaxian origin (see for a review Hilker 2009).

A promising way to learn more about the nature of UCDs is to study their global properties in galaxy clusters and compare them to those of other dwarf galaxies and rich globular cluster systems around central cluster galaxies.

2 Samples of UCDs in nearby galaxy clusters

Finding UCDs is not a straightforward task. They can easily be confused with foreground stars and unresolved background galaxies. It’s like searching needles in a haystack. Indeed, the first UCDs were discovered not until about ten years ago by systematic spectroscopic surveys in nearby galaxy clusters, aiming at confirming the membership of either galaxies or globular clusters (Hilker et al. 1999, Drinkwater et al. 2000). Only now we can say that statistically meaningful samples are becoming available.

In Table 1 the current number counts of UCDs and GCs/UCDs more luminous than ω Cen in various clusters are listed. The Fornax cluster, so far, is the best studied environment with ~ 60 UCDs and > 150 ω Cens. Within its core radius the completeness is of the order of 90%. For the other clusters this value is much lower. In the Virgo cluster data on UCDs still are quite sparse (e.g. Jones et al. 2006), but probably will outnumber all other UCD samples when the Next Generation Virgo Cluster Survey and its spectroscopic follow-up will become available.

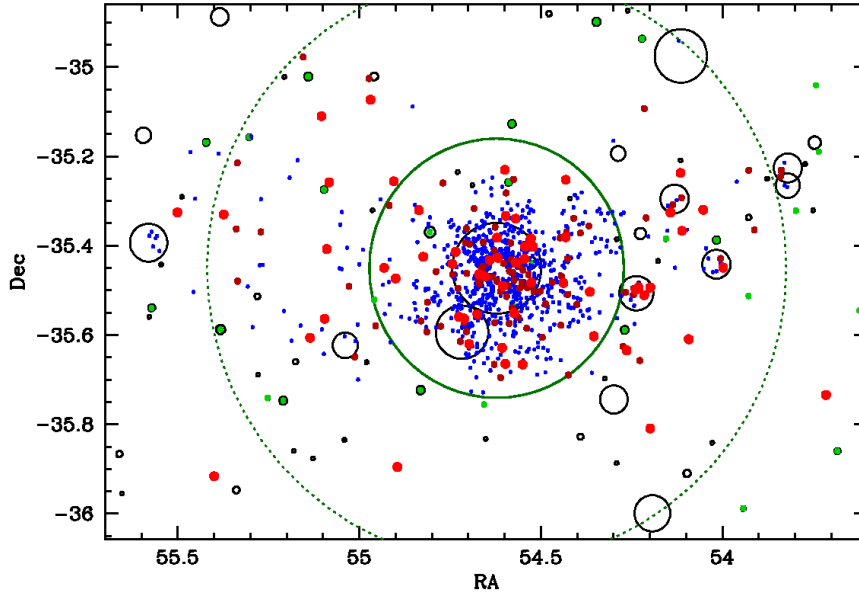


Fig. 1. The central region of the Fornax cluster. The dotted circle indicates the core radius. All objects in this plot are confirmed cluster members. The black circles are the cluster galaxies, nucleated dEs are marked with a green dot. The small blue dots are GCs with $M_V < -8.5$ mag, small red dots ω Cen-like GCs ($M_V < -10.4$ mag), and large red dots UCDs ($M_V < -11$ mag). Objects within the dark green circle were used to derive the cumulative radial number distributions of the different objects (see Fig. 2).

3 Spatial distribution of UCDs

Based on the UCD samples available, one can study their spatial distribution within areas of high number count completeness. As an example, in Fig. 2 the location of GCs, UCDs, nucleated dEs and other galaxies in the central region of the Fornax cluster are shown. All of them are confirmed members, either by radial velocity measurements or morphological classification (in the case of galaxies). As can be seen, many of the UCDs are concentrated around the central cluster galaxy NGC 1399, but also around other major cluster galaxies. Those seem to belong to the globular cluster populations of the individual host galaxies. On the other hand, there exists a fair number of UCDs in the intra-cluster space, well beyond the tidal radii of the major cluster galaxies. Those cannot easily be explained by a ‘normal’ globular cluster population, but rather belong to the cluster population.

When plotting the cumulative radial number distribution of the different stellar systems and galaxies within 110 kpc (the 90% complete area), a clear sequence of concentration becomes apparent (see Fig. 2). From high to low concentration the order is: red (metal-rich) GCs, blue (metal-poor) GCs, GCs/UCDs more lu-

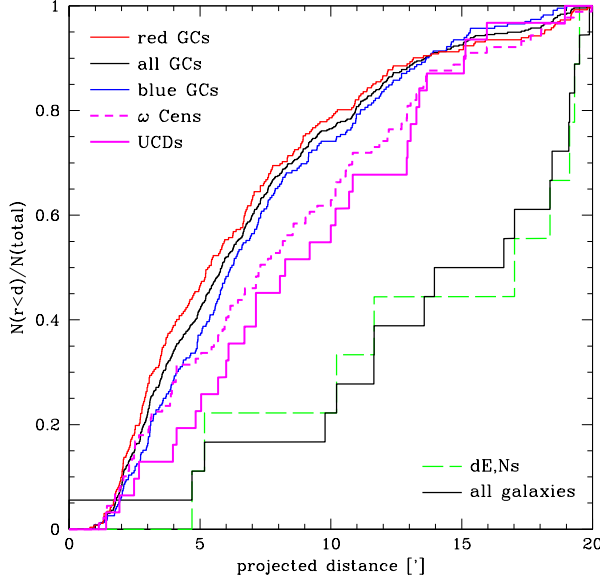


Fig. 2. Cumulative radial number distributions of globular clusters, UCDs, dE,Ns and galaxies within 110 kpc of the central cluster galaxy NGC 1399.

minous than ω Cen ($M_V < -10.4$ mag), UCDs ($M_V < -11$ mag), nucleated dEs, and finally all cluster galaxies. Although UCDs clearly do not share the same distribution as dE,Ns, they also are not as concentrated as globular clusters. This again demonstrates that UCDs seem to be a mixed bag of objects, some being related to the central globular cluster system, others most probably being related to a galaxian formation process, i.e. they might be stripped nuclei of dEs.

The cumulative radial number distributions of UCDs in the other galaxy clusters presented in Table 1 show the same behaviour – despite smaller number counts: UCDs are more concentrated towards the cluster centre than the cluster galaxies, but less concentrated than the central globular cluster systems.

4 UCDs in the context of other hot stellar systems

The photometric and structural parameters of UCDs can be compared to those of other hot stellar systems, in particular globular cluster, nuclear star cluster and early-type dwarf galaxies. In Fig. 3 the colour-magnitude diagram of those systems is presented, assembled from data in the Fornax, Virgo, Hydra I and Centaurus clusters. The colour $(V - I)_0 = 1.05$ mag divides the blue (metal-poor) GCs from the red (metal-rich) ones, showing the well-known colour bimodality. The most luminous, and thus most massive UCDs extend the red GC population to higher luminosities. Some of those might have formed in the same event as the bulk of

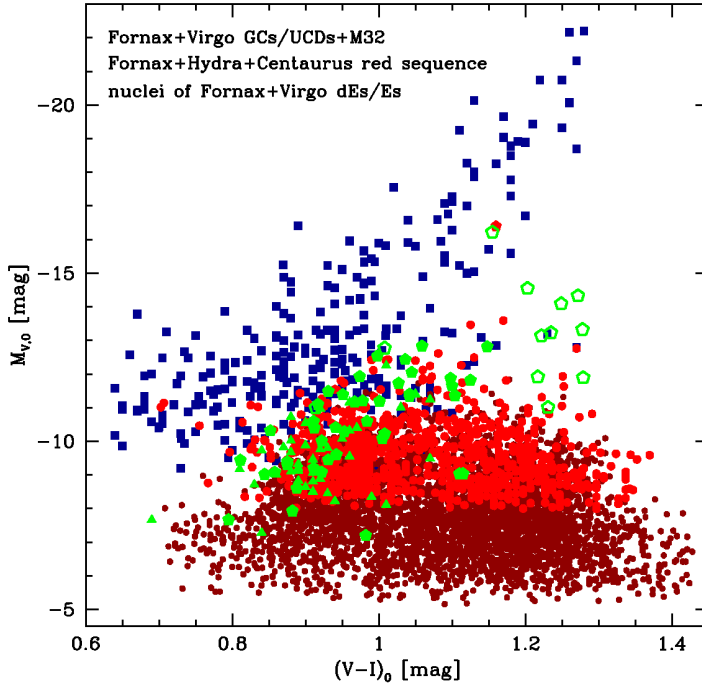


Fig. 3. Colour-magnitude diagram of various stellar systems in the nearby galaxy clusters Fornax, Virgo, Hydra I and Centaurus. Blue squares mark the red sequence of early-type galaxies (Mieske et al. 2007, Misgeld et al. 2008, 2009). The small, dark red dots are GCs around the central galaxies in Virgo and Fornax from the ACS surveys (Peng et al. 2006, Jordán et al. 2009). Light red dots are confirmed GCs/UCDs in Fornax (Schuberth et al. 2010). The red filled hexagon marks M32. The green hexagons and triangles are nuclear star clusters (NCs) of early-type galaxies in Fornax and Virgo (Lotz et al. 2004, Côté et al. 2006), open symbols those of giant galaxies.

the red GCs, which are believed to be related to the bulge/spheroid formation of ellipticals. A plausible scenario for that are major mergers of gas-rich galaxies that are known to create stellar supercluster complexes.

UCDs with blue colours, instead, coincide in the CMD with the location of nuclear star clusters of early-type galaxies. The colour-magnitude relation of NCs falls on top of the blue side of the metal-poor GC sequence, also known as blue tilt (e.g. Harris 2009). Thus, if UCDs are remnant nuclei of disrupted dwarf galaxies they might extend to fainter luminosities and form part of the metal-poor globular cluster systems. The similar size-luminosity relation of UCDs and nuclear star clusters is another intriguing parallel between both types of objects (see contribution by Misgeld et al. in this volume).

The ultimate answer about the nature of UCDs can only be given, if the global, photometric and structural parameters of UCDs are accompanied by detailed kinematic and spectroscopic abundance analyses.

5 Conclusions

Ultra-compact dwarf galaxies are defined through their mass-size relation and enhanced dynamical mass-to-light ratios – roughly occurring for stellar systems with masses $> 2 \times 10^6 M_\odot$. UCDs share some properties of globular clusters as well as of galaxy nuclei, thus they might be an inhomogeneous class of objects. They are mostly concentrated around major galaxies but also are found in the intra-cluster space. As a consequence UCDs are spatially more concentrated than the cluster galaxies but show a wider distribution than the rich globular cluster systems around the central cluster galaxies. Still the studies of the UCD population in nearby galaxy clusters suffer from incompleteness effects. More spectroscopic surveys are needed to get a full account of UCDs. Large samples of well-studied UCDs (i.e. with radial velocities, spectroscopic element abundances and age estimates), like in the Fornax cluster, offer the opportunity to unravel the nature of UCDs via ‘chemo-dynamical’ tagging.

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